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STUDY OF PRETESTING EFFECTS ON ELECTROEXPLOSIVE DEVICES

by M. G. Kelly and R. G. Amicone

Prepared by
THE FRANKLIN INSTITUTE RESEARCH LABORATORIES
Philadelphia, Pa.
for Langley Research Center

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FOREWORD

This program, "Study of Pretesting Effects on Electroexplosive Devices," is being conducted by the Applied Physics Laboratory, one of The Franklin Institute Research Laboratories, under the sponsorship of The National Aeronautics and Space Administration Contract No. NAS1-62-1, Langley Research Center, Virginia.

Key personnel in the work are E. E. Hannum, Manager, Applied Physics Laboratory, R. G. Amicone, Group Leader, and M. G. Kelly.

This is the final technical progress report, Franklin Institute No. F-C1859, covering the period 5 May, 1966 to 5 August 1967. This report is not classified.

ABSTRACT

The answers to a questionnaire which was sent to various NASA installations and their suppliers dealing with the currently used pretesting practices are summarized and discussed. The currents used for bridge resistance and continuity checks vary from 20 μ amps to 20 mamps. No-fire and/or "1 amp, 1 watt" pretests are applied by almost all users and suppliers. Voltage breakdown and dielectric strength tests use voltages ranging from 50 to 1400 volts. Electrostatic tests involve voltages of from 9 to 25 KV applied to the EED from a 500 pf capacitor. The no-fire test was judged to be one of the most severe pretests if applied to EED's intended for actual use.

Experiments were performed on a variety of EEDs using the results of the questionnaire as a guide. A severe version of the voltage breakdown test was used to condition COMMAND squibs, FOX squibs and MASSEY-1000 igniters. Subsequent tests which were run showed no significant changes had occurred in the constant current sensitivity, functioning time, electrostatic sensitivity, and bridgewire power sensitivity due to the conditioning.

A decrease in the constant current sensitivity and an increase in the functioning time and thermal time constant of the DART squib were affected by pulsing with successively increasing constant current pulses of 10 second duration (a conditioning schedule which is more severe than any normally applied pretest). Conditioning the DART squib at the no-fire current level for 72 hours had no significant effect upon these performance parameters.

Conditioning the TA-700 squib with no-fire currents for periods as short as 1 hour caused a significant decrease in the constant current sensitivity and an increase in the functioning time. Longer conditioning caused greater changes in these parameters. No changes were observed in the thermal time constant or the dynamic resistance of the TA-700 squib due to conditioning with no-fire currents or successively incremented pulses.

A technique for the theoretical analysis of pretest effects is presented. Some knowledge of the EED thermal parameters is required for this approach.

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INTRODUCTION

After an EED is manufactured it is usually subjected to a variety of tests which we call pretests. The most common pretest is the continuity or bridge resistance check. Other, more complex, tests involving dielectric strength, r-f susceptability, and electrostatic sensitivity are also used by many manufacturers and users. It was our intention in this project to determine in detail what pretests are used and how they might affect the normal behavior of electroexplosive devices (EEDs).

Our plan was to send out a questionnaire concerning the pretest practices to the manufacturers and users of EEDs. The answers to the questionnaire formed the framework of the experimental study. The experimental study using various EEDs was concentrated on two facets of pretesting which appeared to be possible problem areas - the dielectric strength test and the no-fire test. This report is thus divided up into sections dealing with the answers to the questionnaire, the dielectric strength test and the no-fire test. One additional section discusses the methods used in the experimental studies.

1. CURRENTLY USED PRETEST PRETEST PRACTICES

At the start of this project a questionnaire (See Appendix A) concerning the currently used EED pretesting practices was sent to a number of EED users and manufacturers. Out of 31 questionnaires sent out 14 were answered. The replies are summarized below with special emphasis given to the pretests practices which we have studied in detail. The questionnaire may be referred to in Appendix A for the actual questions asked under each topic.

1.1 Pin-to-Pin EED Pretests

Pin-to-Pin tests, that is, tests in which the test stimulus is applied across the bridgewire or spot charge are of two types. There is the bridge resistance or continuity check and the no-fire or "one-amp, one watt" test.

1.1.1 Bridge Resistance and Continuity Check

The currents used in measuring bridge resistance or continuity may vary from 20 microamperes to 20 milliamperes with 10 milliamperes being the most frequently used value. According to the replies, resistance checks are made on 100% of each lot and, in some cases, repeated up to 30 times. The Alinco resistance tester is the most commonly used instrument for making these tests. Section 1.5 of this report deals with this tester. Table 1 summarizes the replies concerning the bridge resistance checks.

1.1.2 No-Fire and "1 Amp, 1 Watt" Test

Most manufacturers and users of EEDs subject them to a "no-fire" test. A no-fire test consists of passing a constant current through the

Table 1

SUMMARY OF REPLIES CONCERNING BRIDGEWIRE
RESISTANCE CHECKS AND NO-FIRE CURRENT TESTS

	Bridgewire Resistance Check			No-Fire Current Test		
User/Manu. No.	Current Level (ma)	Number of Applications	% of Lot Checked	Length of Application	Number of Applications	% of Lot Tested
1	10	4	100%	5 min	1	5%
2	<20	Varies		5 min	1	Sample
3	10	4		5 min	1	100%
4	5	4-6		30 sec	1	Sample
5	<5	Varies		1 min	1	100%
6	12	30 max		5 min at 160°F	1-2	50%
7	10-20	1-3		5 min	Varies	Varies
8	*	*		*	*	*
9	5	2		*	*	*
10	10	-		5 min	1	Sample
11	10	1-4		5 min	1	15%
12	20 μamps	1		15 min	1	100%
13	5	3-5		*	*	*
14	20	3		5 min	1	Varies

*Test not performed.

bridge which has been experimently determined to have a very low probability of firing the EED. The firing probability level usually chosen is the 0.1% level with 95% confidence. Many users also require that the EED be subjected to the 1 amp, 1 watt level of input power. With some EEDs this level corresponds closely with the no-fire level. In other instances the 1 amp, 1 watt level is below the no-fire current level. Of course many EEDs are designed to be more sensitive and in such cases the 1 amp, 1 watt criteria does not apply.

According to the replies to our questionnaire no-fire currents are applied to EEDs for periods ranging from 30 seconds to 15 minutes. The median application time is 5 minutes. Almost all users and manufacturers apply the test current only once. The percentage of the total lot tested ranges from 5% to 100%. In the case of those repliers who said they subjected 100% of the lot to the no-fire current, an allowance must be made for a possible misinterpretation of the expression "percent of total lot" in the questionnaire. One replier, for instance, said that 100% of his items were subjected to 1 amp, 1 watt for 5 minutes at 160°F. It is doubtful that one would want to use an EED which survived such a test. It is possible that such repliers meant that the no-fire test was run on a sample of 100% of the total lot. Table 2 summarizes the replies concerning no-fire current tests.

1.2 Bridge-to-Case and Bridge-to-Bridge Pretests

The replies to the questionnaire indicate that most users and manufacturers subject their EEDs to bridge-to-case and/or bridge-to-bridge tests of two types: the voltage breakdown or dielectric strength test and the electrostatic test.

1.2.1 Voltage Breakdown or Dielectric Strength

Almost all users and manufacturers who replied use some form of voltage breakdown or dielectric strength test. In general, a voltage of

TABLE 2

SUMMARY OF REPLIES CONCERNING VOLTAGE BREAKDOWN OR DIELECTRIC STRENGTH TEST

User/Manu.* #	Voltage Level AC Volts	Voltage Level DC Volts	Range of Currents AC	Range of Currents DC	No. of Applications	% of lot Tested	Test Instrument Used	Acceptance Criteria
1	-	500	-	-	≈4	100%	-	>10 megohms
2	-	1000	-	50to500μa	-	100%	Mideastern Electronics	>2 megohms
3	-	500	-	none	≈5	100%	Freed	>2 megohms
4	-	250 to 1400	-	10μa	Varies	100%	Douglas Aircraft	Breakdown Between 600 & 1200 VDC
5	-	3.0	-	No Limit	2	100%	Simpson VOM	>2 megohms
6	-	500	-	500 μa	1	100%	Freed	>1 megohm
7	-	1200	-	20 μa	1	100%	Douglas Aircraft	>100 megohms
8		Not		Run				
9	500 to 1000	500	.5 to 1 ma	-	3	100%	General Radio, Slaughter	>10 megohms
10	500	-	.10 ma	-	2	100%	Associated Research	No Breakdown
11	500	-	5 ma	-	1	100%	General Electric	No Breakdown
12	-	500	-	10μa	1-2	100%	Various	>50 megohms
13	500	500	250 μa	-	1	100%	Freed, Slaughter	>100 megohms
14	-	500	-	10ma	2	100%	Freed or General Radio	>2 megohms

*No names are given since some repliers wished to remain anonymous.

50 to 1400 volts is applied from bridge-to-case or bridge-to-bridge for a period of from 5 to 10 seconds. Both a-c and d-c voltages and a variety of test instruments are used. In Section 1.5 of this report the General Radio megohmmeter is discussed in relation to pretesting EEDs. Table 2 summarizes the replies concerning voltage breakdown or dielectric strength.

1.2.2 Electro-Static Test

In the electrostatic test a voltage ranging from 9 to 24 kilovolts is discharged from a 500 picofarad capacitor across the bridge-to-case or bridge-to-bridge of the EED being tested. The number of applications of the test voltage varies from 1 to 5 times, and in most cases 100% of the lot is tested (100% of sample?). The criteria for acceptance is usually "no-fire" but such conditions as "safe and operable" and "no degradation" are also used for judging acceptability.

1.3 RF Susceptibility Tests

The replies concerning RF pretesting of EEDs were incomplete, not available or in most cases, the tests were simply not run. Of those repliers who said they ran RF pretests, power levels of "4 times normal" and "100 MW/CM^2 run between 2 to 10,000 megahertz" were typical.

1.4 Other Tests

A variety of additional tests are run by the various users and manufacturers. Thermal time constant, leak test, pressure test, all fire, and functioning time are examples. Some of these tests are destructive and thus are usually performed on a small sample of the total EED lot.

1.5 Equipment Used

A variety of equipment is used for the various pretests. During our studies three of the instruments frequently used in pretesting were available to us for test purposes.

The General Radio Megohmmeters, types 1862-B and 1862-C (a more recent model), which are frequently used for measuring dielectric strength were tested to determine if the application of the test voltage across the EED produced any excessive switching transients. Using an oscilliscope we established that neither model of the General Radio Megohmmeter supplied any voltage greater than 500 volts across the EED when applied with the self contained switches.

The ALINCO igniter circuit tester made by the Alleghany Instrument Co. and the model E-80 Blasting Galvanometer made by the Gray Instrument Co. are used extensively for resistance and continuity checks. A routine check was made of maximum available measuring current and waveforms generated when the instruments are placed in an EED circuit. Neither instrument produced any measurable switching transient when switching in and out of a typical EED circuit, either with the built-in switch or a mercury relay. The E-80 blasting galvanometer delivered a maximum current of 7.5 milliamperes to a short circuit load. The ALINCO tester delivered a maximum current of 4.8 milliamperes under similar conditions.

These relatively simple tests on these tests instruments showed that no unsafe or unexpected conditions were likely during pretesting.

2. METHODS OF EVALUATION

In the preceding section of this report the various EED pretests currently employed by manufacturers and users were discussed. An important objective in this program was to determine if there were any detectable effects on an EED due to these pretests. Two approaches are possible to assess pretest effects: theoretical approach where both the input and response parameters of a given EED are studied and experimental approach where actual EEDs are used in simulated pretests. Although we have employed only experimental techniques in this study a theoretical approach is discussed for possible use in future studies.

2.1 Theoretical Method

2.1.1 Pin-to-Pin Pretests

If the value of certain EED bridgewire parameters can be determined either by calculation or measurements it is possible to estimate bridge-wire temperature as a function of input current. The following steady state relationship given by Rosenthal[1] is applicable to hot wire type EEDs:

$$\theta = \frac{I^2 R}{\gamma - I^2 R\alpha}$$

where θ = bridgewire temperature, °C

I = bridgewire current, amperes

R = bridgewire resistance, ohms

γ = bridgewire heat loss factor, watts/°C

α = bridgewire temperature coefficient of resistance ohms/ohm-°C.

The bridgewire heat loss factor (γ) is a measure of the electrical power which must be supplied to the bridgewire to overcome the heat loss to the surrounding explosive material and binding parts, and maintain a fixed

[1] L.A. Rosenthal, NavOrd Report 6684, "Electrothermal Equations for Electrothermal Devices", Aug. 1959.

temperature. The temperature coefficient (α) is a measure of the resistance change of a material per degree temperature rise. The rest of the factors are self explanatory.

Difficulty in obtaining the values of α and especially γ will be a major limiting factor in this technique. The latter factor can usually be obtained only by direct measurement.

If a relationship between input current and bridgewire temperature can be obtained with the preceding equation, then the next step is to estimate or determine the highest bridgewire current to which the EED will be subjected during a given pin-to-pin type pretest. As we have mentioned in Section 1 the two prominent types of pin-to-pin pretests to which EEDs are normally subjected are the resistance or continuity test and the no-fire test.

Figure 1 illustrates diagramatically the relative relationship of the amplitude of the resistance and continuity test currents to the amplitude of the firing pulse which is used to initiate an EED in its final application. Note that each line which represents an application of a measuring current is always less than the mean-5σ current level which may be considered close to the 0.1% firing level with 95% confidence (often known as the "no-fire" level). The spacing between the lines represents the time intervals which may elapse between measuring pulses. Of course the evenness of the spacing is not significant since resistance and continuity tests may be made minutes or days apart. The number of lines is, likewise, not significant since our survey showed that some EEDs are subjected to only one measuring pulse whereas others are subjected to several before the final application. The firing pulse which initiates the EED in its final application is usually higher in current magnitude than the mean+5σ firing level which is close to the 99.9% with 95% confidence firing level ("all-fire level").

In a manner similar to Figure 1 the relationship of the no-fire or 1 amp, 1 watt pretest pulses to the firing pulse is illustrated in Figure 2. In this figure the no-fire test pulses are represented by

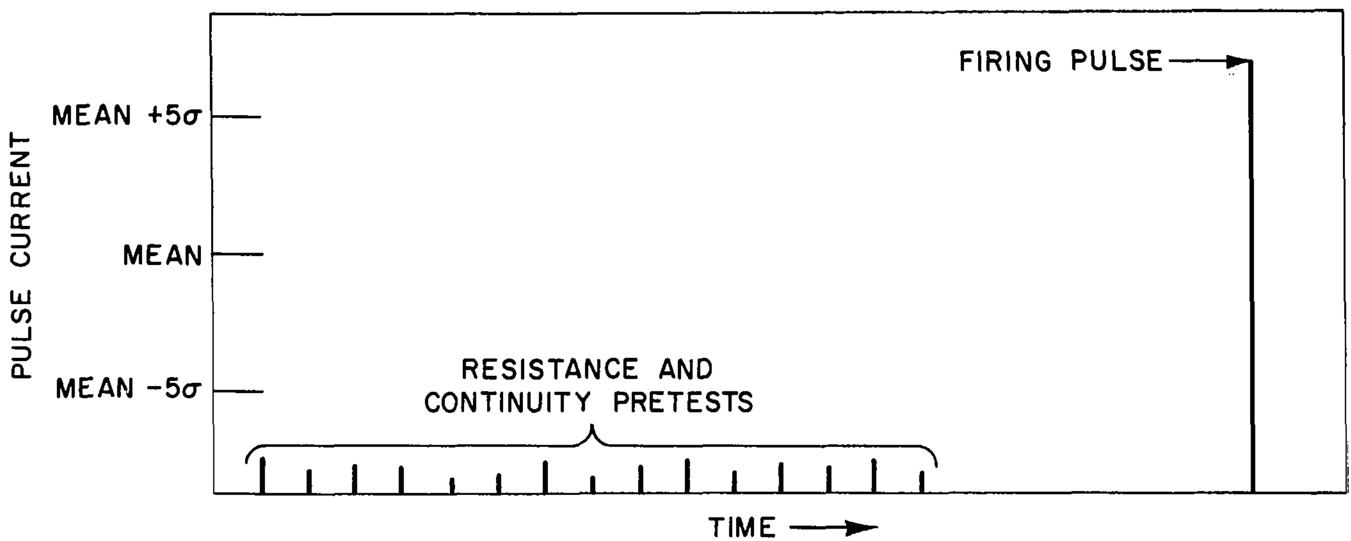

FIG. 1. RESISTANCE AND CONTINUITY TESTS

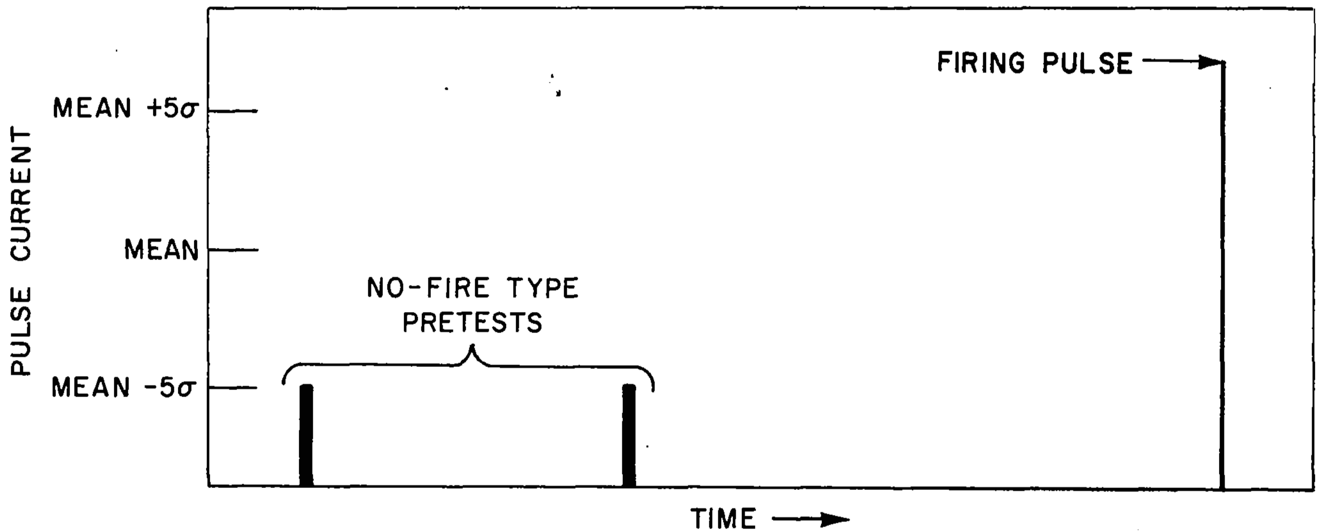

FIG. 2. NO-FIRE TESTS

thicker lines than those of Figure 1 because the no-fire pretest pulses are usually applied for 5 minute periods - a relatively long time compared to the resistance and continuity tests. If a no-fire test is applied at all to an EED it is only applied 1 or 2 times; thus, only two pulses are shown. The magnitude of the no-fire pulses is usually about the mean-5σ current firing level which is a good conservative estimate for the 0.1% firing level with 95% confidence.

In Figure 3 the combination of the resistance pretests, the no-fire pretests and possible environmental background stimuli are illustrated diagrammatically in relation to the firing pulse. The possible environmental stimuli which we have shown in this figure included steady monitoring currents which are often used in EED-bearing vehicles, and unintentional currents to the bridgewire resulting from crosstalk in wiring harnesses and stray r-f pickup in the vehicle. Although these environmental stimuli can exhibit undesireably high current levels it is assumed that they are usually comparable to the normal resistance and continuity current levels of 5 to 20 milliamperes used in pretests.

Figure 3 illustrates then, that the most severe pin-to-pin pretest is the no-fire test since current levels of approximately mean-5σ are applied to the EED. By using the firing data (the mean and standard deviation,(σ) as determined by the Bruceton procedure or other suitable technique) the current corresponding to the mean-5σ level can be calculated for a given EED. The temperature of the bridgewire can then be determined for this current level.

Knowing the maximum steady state temperature to which the explosive material around the bridge would be subjected to during a pretest might enable us to make some sound conclusions concerning the effects of the "worst-case" pretest. A knowledge of the effects of temperature upon the explosive or materials in an explosive mixture is often obtainable from DTA (differential thermal analysis) curves, physical constant tables and other related sources. If it is known, for instance, that for a

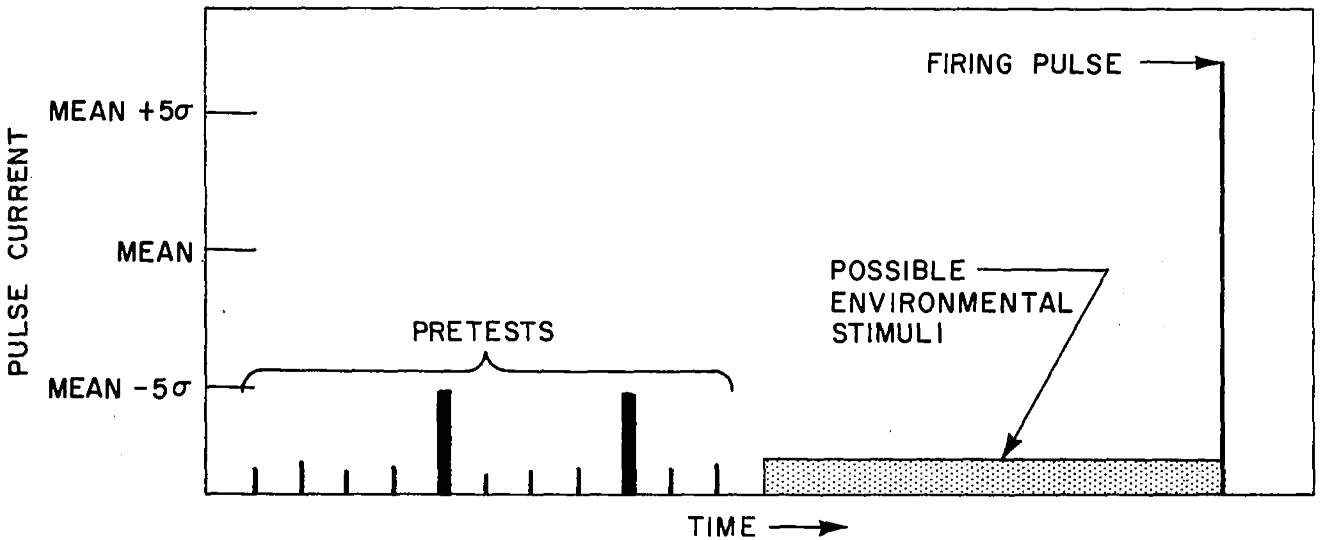

FIG. 3. ALL PRETESTS COMBINED WITH ENVIRONMENTAL STIMULI

particular EED the "no-fire" temperature due to a pretest is 200°C and an ingredient in the explosive mixture undergoes decomposition at 190°C then we may expect some effect due to the pretest. The explosive mixture could change its sensitivity, for instance.

We realize that the foregoing type of approach may require information about the bridgewire structure and the explosive materials which is not always readily available. It should be pointed out, however, that it may often prove easier to gather such information than to perform some of the various destructive tests which we will describe in the next section. Where costs and/or the number of EEDs available for pretest evaluation are limited, a theoretical approach may be the only answer.

2.1.2 Bridge-to-Bridge and Bridge-to-Case Tests

In attempting to predict what effects might be expected on the firing characteristics of an EED due to electrostatic and voltage breakdown tests we are limited considerably by lack of information on the effects of high voltages on explosives. Simple calculations using Ohm's law will show that the currents and powers involved in both the voltage breakdown and the electrostatic tests are extremely small when we consider that the bridge-to-case resistance of most EEDs is 1 megohm or more. This seems to dictate that any effect due to the electrostatic and voltage breakdown tests would be very localized within the EED.

It is known that both types of pretests have caused EEDs to fire while being tested. It is also conceivable that the application of electrostatic and voltage breakdown pretests could cause an EED to become more sensitive to these modes of firing. Determination of these effects and other less obvious effects is presently limited to experimental techniques in which actual EEDs are employed, i.e. no simple theoretical method exists for the evaluation of static and voltage breakdown pretest effects.

2.2 Experimental Methods

In our studies of the effects of pretests we have used a number of experimental methods. Among the methods used are the successive increment technique, no-fire pulsing, and the non-destructive technique. Measurements of commonly used EED parameters such as the 10 second constant current sensitivity, functioning time, thermal time constant and dynamic resistance were also used extensively in pretest evaluations. Most of the techniques and parameters mentioned are described in detail in Appendix B; however, the main techniques are discussed briefly below.

2.2.1 Successive Increment Technique

Since the successive increment test tends to exaggerate the effects of pretests it is used as a means of roughly screening EEDs before more definitive tests are employed. If an EED exhibits no change in sensitivity due to the successive increment test it is doubtful that it will be adversely affected by any pin-to-pin pretests.

2.2.2 No-Fire Pulsing

A more definitive technique is to subject a quantity of EEDs to constant current pulses at the mean-5σ level and then evaluate the various EED parameters of the pulsed items such as the 10 second, constant current sensitivity, functioning time, thermal time constant, etc. for significant changes. A disadvantage of this and similar techniques in which EEDs are subjected to current levels with firing probabilities of less than 50% (the mean) is that a large quantity of EEDs must be used to define the degree of the pretest effect, if any.

2.2.3 Non-Destructive Technique

The non-destructive technique makes use of the product $R_o \left(\frac{\Delta R}{\Delta P}\right)$ (see Appendix B) which has been shown to be related to the constant current sensitivity for many EEDs. Pretest currents such as the mean-5σ current can be applied to an EED and, subsequently, the product $R_o \frac{\Delta R}{\Delta P}$ is measured to assess the effects, if any, due to the present current. When testing an EED for pretest effects for the first time, say with the successive increment technique, the non-destructive technique is an excellent backup test. When more information is known about the EED the non-destructive test may be used as a primary means of analysis.

3. EFFECT OF THE 500 VOLT MEGOHMMETER TEST ON VARIOUS EEDs

We were especially interested in the effects produced in an EED by the 500 volt megohmmeter (or "megger")test. In order to assess any effects, the EEDs being studied were subjected to various control tests which established the "normal" behavior of the EED under the given conditions. After the "normal" behavior was established, a number of fresh EEDs were subjected to a 500 volt preconditioning test. The control tests were again run on these conditioned items and the results compared with the "normal" test results.

The 500 volt preconditioning test was chosen to simulate adverse testing conditions. According to the replies listed in Table 2 in Section 1.2 most criteria for acceptance involve the measurement of pin-to-case resistance. This being the case, it is conceivable that someone making a check of pin-to-case resistance could apply the 500 volts to the EED for a period as long as 10 seconds in order to obtain the reading and, perhaps, record it. Also, a situation in which the measurement was repeated as many as 10 times might also occur. Thus, we arrived at a 500 volt preconditioning test which consists of applying 500 volts, pin-to-case, for ten consecutive 10 second periods. The time between voltage application is just enough to allow complete discharge of the 500 volts. In all tests, the positive voltage was applied to the pins and the case was grounded.

3.1 COMMAND Squib

The COMMAND squib is a low output wire bridge device which is often used in explosively activated switches. The average leads-to-case resistance is 10^5 megohms. Four different control tests were run on the COMMAND squib (1) constant current sensitivity, (2) functioning time as a function of firing current and (3) electrostatic sensitivity, and (4) bridgewire power sensitivity. The results of the control tests and the tests in which the squibs were conditioned with the 500 volt megohmmeter test as previously described are discussed in the paragraphs which follow. Details of the control tests will be found in Appendix B.

3.1.1 Constant Current Sensitivity

Using the Franklin Institute Laboratories Universal Pulser (FILUP), which was developed for Picatinny Arsenal under contract No. DA-36-034-501-ORD-3115RD, the constant current sensitivity of 40 COMMAND squibs to a 10 second pulse was determined by the Bruceton technique. Forty squibs were then conditioned as described in Section 3 and evaluated for constant current sensitivity. The results are compared in Table 3.

Table 3

RESULTS OF CONSTANT CURRENT TEST ON THE COMMAND SQUIB

	Mean (milliamperes)	Std. Deviation (log units)
Control items	446.7	.0176
Conditioned items	451.9	.0227

There is no significant difference in either the mean or the standard deviation for the conditioned and unconditioned sqibs.

3.1.2 Functioning Time

The COMMAND squib exhibits a low intensity light output. For this reason, accurate functioning times could not be readily obtained with our photoelectric and chronographic equibment. The functioning time measurements of these squibs were therefore abandoned.

3.1.3 Electrostatic Sensitivity

Since the 500 volt "megger" test is a pin-to-case test, it occurred to us that the effects on the pin-to-case resistance might be reflected in the pin-to-case electrostatic sensitivity. It was our intention to determine static sensitivity by applying voltage pulses in increasing 500 volt steps starting at 1000 volts from pin-to-case until the squib was ignited or breakdown occurred. The apparatus shown in Figure 4, which simulates the capacitance and resistance of a human being, was used to deliver the static pulses.

The plug configuration of the COMMAND squib was such that external arcing from leads-to-case occurred at about 7000 volts on all squibs. Because of this, the test on these EEDs was abandoned.

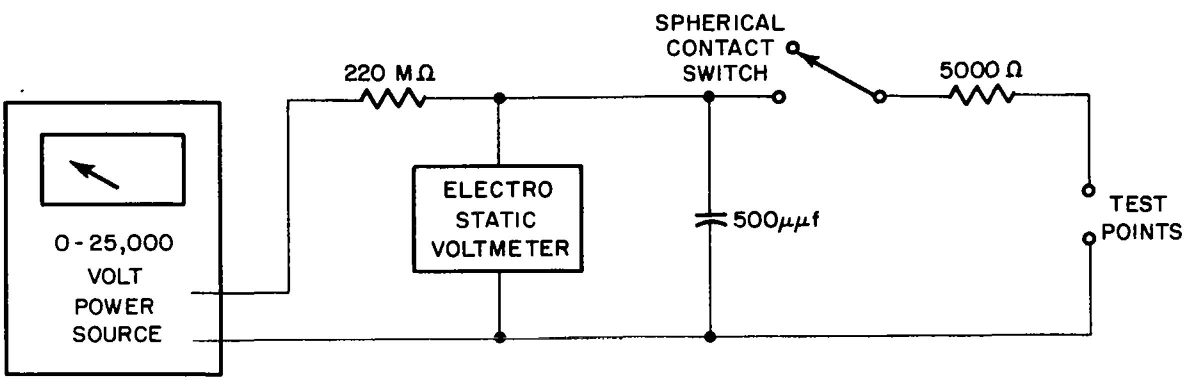

Fig. 4 - Static Discharge Test Circuit

3.1.4 Bridgewire Power Sensitivity

Using the technique described in Appendix B the bridgewire power sensitivities of twenty COMMAND squibs were measured and found to average 0.0211 ohms per watt for unconditioned squibs. Twenty conditioned squibs averaged a power sensitivity of 0.0206 ohms per watt. Thus, the 500 volt "megger" test did not affect the bridgewire power sensitivity which has been shown to be related to the constant current sensitivity. The constant current Bruceton test described in Section 3.1.1 seems to verify these results.

3.2 Effects of the 500 Volt Megohmmeter Test on the FOX Squib

The FOX squib is a hot wire bridgewire lead EED with an energetic output. As its designation implies, it is an experimental model. It was employed in the 500 volt megger tests because we had a small quantity available. The average leads-to-case resistance is 3×10^4 megohms.

Due to the limited number of available FOX squibs, the constant current sensitivity and the bridgewire power sensitivity tests were not made on these EEDs. The functioning time tests (which should reflect constant current sensitivity) and the electrostatic sensitivity tests were run.

3.2.1 Functioning Time as a Function of Firing Current

Six FOX squibs were fired at each of five different constant current levels. The pulse width was held constant at 10 seconds. The same test was repeated using FOX squibs which had been conditioned with the 500 "megger" test as per Section 3. The average functioning times at each current level for conditioned and unconditioned squibs are listed in Table 4.

Table 4

FUNCTIONING TIMES OF CONDITIONED AND UNCONDITIONED FOX SQUIBS

Current Level (amperes)	Average Functioning Times (microseconds) Unconditioned	Conditioned
1.5	1776	1698
2.5	679	730
4.5	459	412
7.0	306	300
10.0	224	316

A comparison of the functioning times of the two groups of FOX in the table shows that the megger test has no significant effect upon these functioning times.

3.2.2 Electrostatic Sensitivity

The static discharge test described in Section 3.1.2 was run on 20 unconditioned and 20 conditioned FOX squibs. The voltages at which firings occurred for each group of 20 squibs are listed in Table 5.

Both the conditioned and the unconditioned FOX squibs fired at an average electrostatic voltage of 18 to 21 kilovolts. Also, approximately 30% of the squibs in each group of 20 fired. It appears that no effect upon static sensitivity was brought about by the 500 volt megohmmeter check.

The plug, headers, bridgewire, and case of the FOX squibs are identical to those of the DART squib. We felt, therefore, that megohmeter and electrostatic tests were not called for with the DART squib. Furthermore the tests described later in this report required almost all available DART squibs.

Table 5

STATIC FIRING VOLTAGE* FOR CONDITIONED AND UNCONDITIONED FOX SQUIBS

Static Firing Voltage (kilovolts)	
Unconditioned	Conditioned
22	25
22	24
17	21
15	21
14	20
	13

*Voltage increased in 500 volt steps starting at 1000 volts. Data shown in table results for individual squibs.

3.3 MASSEY-1000 Igniter - Electrostatic Sensitivity

The 1000 igniter is a wire bridge, pin type connector EED (the average pins-to-case resistance is 3×10^3 megohms) which produces a non-explosive output suitable for rocket ignition. Only a few of these igniters were on hand, therefore only an electrostatic test was run. Ten unconditioned igniters did not fire up to 25 kilovolts, neither did the conditioned igniters.

One interesting aspect of the static test was that the initially measured pins-to-case resistance of the conditioned igniters decreased by approximately 65% after they were subjected to the electrostatic pulses. This may be due to the effect of the static pulses upon the dielectric materials (glass and plastic) in the base of the igniter.

4. EFFECTS OF PIN-TO-PIN PRETESTS ON VARIOUS EEDs

A major part of the effort on this project was devoted to a study of the effects of pin-to-pin pretests (discussed in Section 1.1) on the DART squib and the TA-700 squib. Successive increment pulsing and no-fire pulsing, both discussed in Section 2.2, were used to condition the squibs. The subsequent changes in the normal values of constant current, functioning time, dynamic resistance, thermal time constant, and bridgewire power sensitivity were taken to be indicative of the degree to which a given pretest might affect these squibs. Relatively large quantities of DART and TA-700 squibs were available so that often, variations of the same test were run. In the following sections the studies on these squibs are organized according to parameters which was measured such as constant current sensitivity or thermal time constant. Details of the various techniques used to measure each parameter are included in Appendix B.

4.1 DART Squib

The DART squib is an aluminum cased squib with insulated wire leads. It has a metal alloy/potassium percholorate main charge, an intermediate charge, and a dipped or spotted initiation charge of lead thiocyanate and potassium chlorate. The deflagrating output of the squib is rather mild.

4.1.1 Constant Current Sensitivity

Using the Bruceton technique the mean sensitivity of the DART squib to a 10 second constant current pulse was found to be 1.310 amperes, the standard deviation was .03220 log units. The data sheet and all calculations are shown in Appendix C.

The mean-5σ level for the DART squib can be calculated from the Bruceton data to be 0.904 amperes for a 10 second pulse width. After the first current level of M-5σ (M=mean) was applied, the current was increased by fixed increments (ΔI) of 20 milliamperes. Ten squibs were thus subjected to pulses of increasing current level until the squibs fired. The results of this test are summarized in Table 6.

Table 6

RESULTS OF SUCCESSIVE INCREMENT TEST
ON DART SQUIBS, ΔI = 20 MILLIAMPERES

Squib No.	Firing Level Amperes
1	1.78
2	1.74
3	1.70
4	1.84
5	1.64
6	1.64
7	1.68
8	1.66
9	1.84
10	1.74

Average Firing Current = 1.73 amperes
Mean Firing Current (From Bruceton Test) = 1.310 amperes

The average firing current in the successive increment test was 1.73 amperes. Since the mean firing current of unprepulsed DART squibs as determined by the Bruceton test (discussed in Section 2.1) is 1.31 amperes we can conclude that the sensitivity of the squib is affected by the prepulses of the successive increment test.

A second successive increment test was run on five DART squibs using an increment of 40 instead of 20 milliamperes. The results of this test are summarized in Table 7.

Table 7

RESULTS OF SUCCESSIVE INCREMENT TEST ON DART SQUIBS, ΔI = 40 MILLIAMPERES

Squib No.	Firing Level Amperes
1	1.60
2	did not fire
3	1.44
4	1.52
5	1.68

Since one squib did not fire (the current level of the firing pulse was increased to the M+5σ level after which further pulsing was stopped) no average firing current is given. We note, however, that none of the five squibs fired at the normal mean firing level of 1.310 amperes. We conclude from these tests that the DART squib can be desensitized by the application of successively increasing constant current pulses. Of course, as we have mentioned previously this test is most severe and does not necessarily mean that any pin-to-pin pretest will change the normal constant current sensitivity.

In order to see if there was any effect on sensitivity due to the pretest which our survey showed to be most severe - the no-fire test - we subjected 22 DART squibs to the calculated no-fire current for a period of 72 hours. After the squibs were subjected to this current level, which was calculated to be 0.905 amperes, their sensitivity to 10-second pulses of constant current was determined with a Bruceton test. The mean was found to be 1.328 amperes and the standard deviation in log units was 0.007. When these values are compared to the normal mean of 1.310 amperes and standard deviation of 0.0322 log units we note what appears to be a significant difference only in the standard deviations. Since there was no great change in the mean sensitivity and time did not permit the complete evaluation of apparent effect on standard deviation, no further tests were run.

4.1.2 Functioning Time

During the successive increment prepulsing test the functioning time of the DART squibs was monitored. The functioning times are listed in Table 8. The normal functioning time from the control Bruceton test is also given.

Table 8

FUNCTIONING TIMES OF DART SQUIBS USED
IN SUCCESSIVE INCREMENT TEST, ΔI = 20 MILLIAMPERES

Squib No.	Functioning Time Seconds
1	7.71
2	8.51
3	7.51
4	9.09
5	6.79
6	6.14
7	9.68
8	7.66
9	8.17
10	7.97

Average Functioning Time = 7.92 seconds
Average Functioning Time from Bruceton Test = .0391 seconds

We note with interest that the application of successively incremented pulses causes the normal functioning time to be lengthened by two orders of magnitude. This means the squib has been severely degraded and the margin of reliability of firing with a given electrical stimulus will be curtailed. One should note, however, that the successively incremented pulse test is specifically designed to promote degradation if there is a tendency in this direction.

Table 9 lists the functioning times of unconditioned DART squibs and also DART squibs which were conditioned at the no-fire level (m-5σ) and a slightly higher level of m-4σ. Both groups were fired at the m+5σ level since this level represents a realistic firing pulse (see Section 2.1.1).

Table 9

FUNCTIONING TIMES OF CONDITIONED AND UNCONDITIONED SQUIBS FIRED AT THE MEAN+5σ CURRENT LEVEL

Functioning Time (millisec.)		
Conditioned Squibs		Unconditioned Squibs
mean - 5σ	mean -4σ	
13.73	32.91	20.37
18.84	23.27	27.45
25.93	29.55	25.34
27.72	29.59	21.60
18.52	17.54	29.74
15.31	22.69	24.03
17.75	15.96	22.45
16.79	25.77	18.26
19.12	15.49	20.66
27.88	22.24	19.11
Avg.=20.16	Avg=23.50	Avg=22.90

As in the case of the DART pulsed at the mean-5σ level, the DART pulsed at mean-4σ level showed no significant change in the functioning time. A possible conclusion which we might draw from these results is that the lengthening of the functioning time seen as a result of the successive increment test is due to pulses above the mean-5σ or mean-4σ levels. Apparently, the mechanism which causes the DART squib's functioning time to be lengthened requires higher temperatures than those supplied by these pulse levels.

Table 10

DYNAMIC RESISTANCE MEASUREMENTS OF CONDITIONED AND UNCONDITIONED DART SQUIBS

Current (amps)	Dynamic Resistance (ohms/sec.)	
	Conditioned	Unconditioned
3.2	7.14 6.59 7.80 Avg.= 7.17	9.76 6.80 11.7 Avg. = 9.41
5.5	48.8 47.6 50.1 Avg. =48.8	33.8 35.1 27.9 Avg. =32.3
8.5	136.3 138.3 117.5 Avg.130.7	136.7 122.5 117.6 Avg. =125.6

4.1.3 Dynamic Resistance

The dynamic resistance of unconditioned, new DART squibs was measured at currents of 3.2, 5.5, and 8.5 amperes using the technique described in Appendix B. A quantity of DART squibs was then pulsed with 10 second, constant current according to the successive increment technique. A difference in pulse levels of 20 milliamperes was used and the pulsing was stopped when the current level reached 1.60 amperes. The level of 1.60 amperes was judged by tests discussed in Section 4.1.1 to be the highest current which the DART squib could bear without actually firing.

The dynamic resistance of the conditioned squibs was measured at 3.2, 5.5, and 8.5 amperes and compared with the unconditioned squibs. The dynamic resistances of the both groups of DART squibs are listed in Table 10 and plotted in Figure 5. There appears to be no significant change in the dynamic resistance characteristics of the DART squib due to the successive increment pulses which were applied.

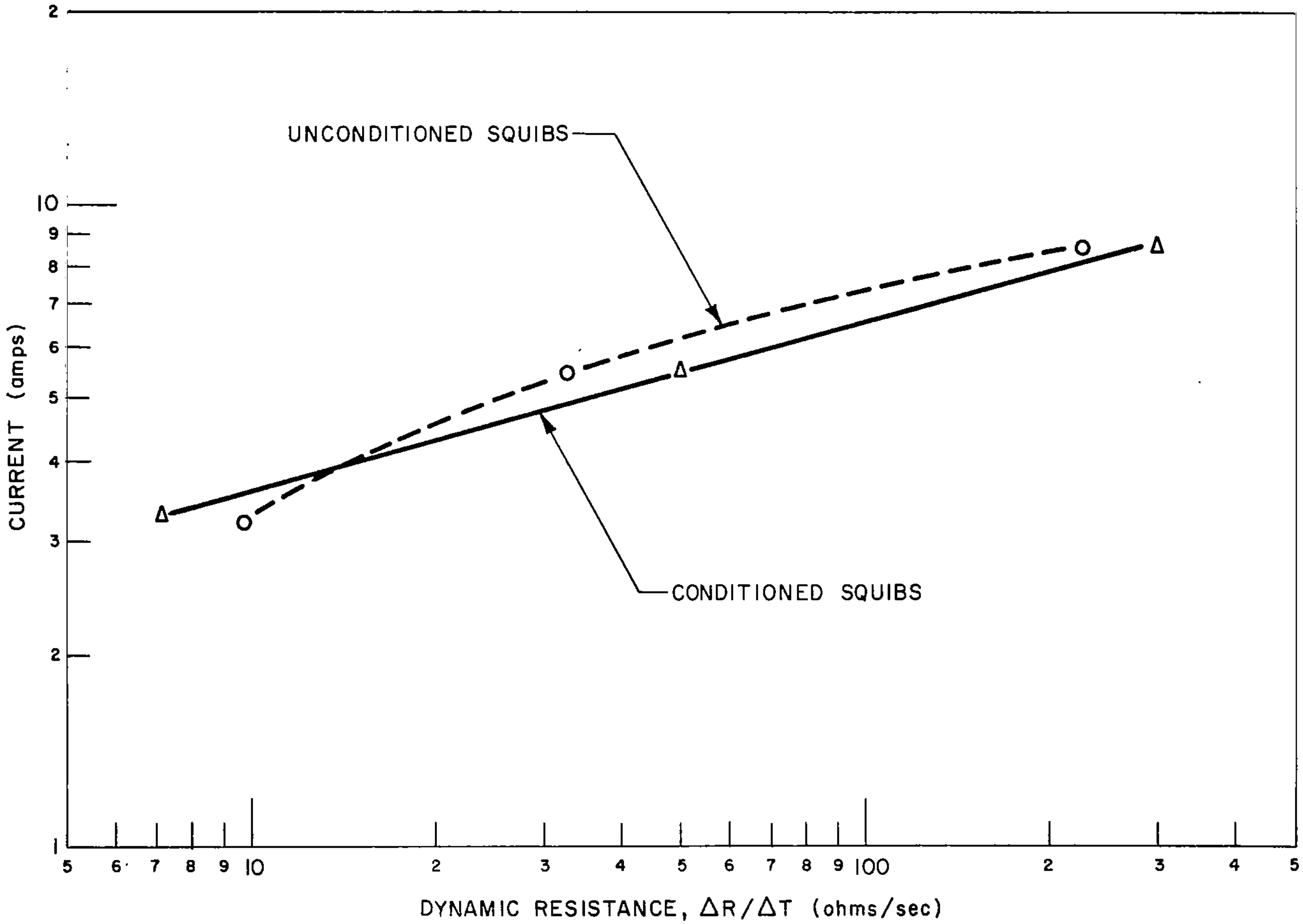

FIG.5. DYNAMIC RESISTANCE OF CONDITIONED AND UNCONDITIONED DART SQUIBS

4.1.4 Thermal Time Constant

The thermal time constants of a quantity of new, unconditioned DART squibs were determined using the technique described in Appendix B. Another quantity of these squibs was subjected to 10 second, constant current successively incremented pulses. The pulses were started at the m-5σ level and increased in 20 milliampere steps until a level of 1.60 amperes was reached. The test was stopped at 1.60 for the same reason mentioned in the previous section and the thermal time constants of the pulsed squibs were determined.

Table 11 lists the thermal time constants of the pulsed and unpulsed DART squibs. We note that the average thermal time constant of the conditioned squibs is slightly longer than that of the unconditioned squibs. Changes in the heat transfer parameters at the bridgewire-explosive interface have probably caused this change.

4.1.5 Bridgewire Power Sensitivity

Using the technique described in Appendix B five DART squibs were measured to determine the bridgewier power sensitivity. The same five squibs were then subjected to successive increment tests using an increment of 40 milliamperes. The prepulsing was stopped at the mean sensitivity since higher pulse levels might have fired the squibs. The bridgewire power sensitivity was again measured. The results of these measurements are shown in Table 12.

In general the prepulsed DART squib shows a slight decrease in bridgewire power sensitivity. If the trend is real it would indicate desensitization of the squib since previous studies[2] have shown that with constant current the firing level = $k_1\left(\frac{1}{R_o \frac{\Delta R}{\Delta P}}\right) + k_2$ where k_1 and k_2 are constants and R_o $\Delta R/\Delta P$ is the bridgewire power sensitivity. It is obvious that if this relationship holds true for EEDs desensitized by some form

[2] Under Army Contract No. DA-36-034-501-ORD-3115RF for Picatinny Arsenal. Reported in FIRL reports MU-A2357-10 through 43.

Table 11

THERMAL TIME CONSTANTS OF CONDITIONED AND UNCONDITIONED DART SQUIBS

Thermal Time Constant (milliseconds)	
Conditioned	Unconditioned
10.6	8.6
10.0	8.7
10.7	9.3
10.9	8.5
10.9	8.4
12.1	10.6
11.7	10.6
11.3	9.5
13.7	8.8
12.6	9.4
Avg.=11.5	Avg.=9.27

Table 12

COMPARISON OF BRIDGEWIRE POWER SENSITIVITIES OF DART SQUIBS BEFORE AND AFTER PREPULSING

Squib No.	Bridge Power Sensitivity(ohms^2/watt)	
	Conditioned	Unconditioned
1	Fired at Mean	.0158
2	.0184	.0212
3	.0087	.0204
4	.0215	.0173
5	.0115	.0185
	Avg. = .0150	Avg. = .0186

of preconditioning (static, heat,dielectric tests, continuity checks, etc.) then the measurement of bridgewire power sensitivity may be a very useful tool for assessing any possible degradation.

4.2 TA-700 Squib

The TA-700 squib is a wire lead EED with a deflagrating output. Various delay times ranging from 0.1 seconds to 1.0 seconds are available. The squibs which we have used in this test series have a 0.3 second delay time. The squib has an ignition spot of potassium chlorate and LMNR (lead mononitroresorcinate) and binders. The spot is suspended solely by the bridgewire binding posts and does not touch the surrounding ferrule nor the delay column igniter. This unique feature may be the cause of the squibs apparent sensitivity to certain pretests.

4.2.1 Constant Current Sensitivity

Using the Bruceton technique, the mean sensitivity of the TA-700 squib lot TA7-77-02 to 10 second constant current pulse was found to be 251.4 milliamperes with a standard deviation of 0.01137 log milliamperes. The data sheet and all calculations for this test are in Appendix C.

As in the case of the DART squib, the TA-700 squibs were subjected to successively increasing constant current pulses of 10 seconds duration to gain a rough idea of the susceptibility of this EED to pretests. We used current increments of $\Delta I = 1$ milliampere, 5 milliamperes, and 10 milliamperes starting at the M-5σ level of 220.5 milliamperes and continuing to the M+5σ level of 286.5 milliamperes. Ten out of ten squibs prepulsed with $\Delta I = 1$ milliampere did not fire at the M+5σ level. Five out of five squibs prepulsed with $\Delta I = 5$ milliamperes and five out of five prepulsed with $\Delta I = 10$ milliamperes also did not fire when taken to the M+5σ current level. A definite alteration in firing sensitivity has thus occurred due to the prepulses. It should be stressed here that the severity of the effect has not been precisely defined. For the TA-700 squib the number of prepulse levels between the $M \pm 5\sigma$ levels was 67 for $\Delta I = 1$ ma, 13 for $\Delta I = 5$ ma, and 7 for $\Delta I = 10$ ma. In the case of the DART squib there were 50 levels for $\Delta I = 20$ ma and 25 levels for $\Delta I = 40$ ma. The fact that 7 prepulses caused desensitization of the delay squib at the $M+5\sigma$ level while 50 prepulses did not always cause desensitization of the DART squib at the same level is the basis for our relative comparison of the prepulse effect.

In order to find our if the TA-700 squibs had been greatly desensitized by the prepulses (they would not fire at the $M+5\sigma$ level which is approximately equivalent to the 99.9% firing level with 90% Confidence) five of the prepulsed squibs were pulsed with 1.0 ampere. All five squibs fired with their average functioning time being about 0.3 seconds (the built-in delay time).

Since the TA-700 squib seemed to be radically affected by the successive increment pulses, further tests were performed using a less severe form of conditioning stimulus. Groups of 25 squibs were subjected to the calculated $M-5\sigma$ current level of 220.5 milliamperes for periods of time ranging from 1 to 72 hours. After the conditioning of each group the 10 second, constant current sensitivity was determined by the Bruceton technique. This test series was performed on two different lots of the TA-700 squibs. The test results are tabulated in Table 13 and plotted in Figure 6.

Figure 6 clearly shows that the application of the no-fire current for even 1 hour causes a decrease in the constant current firing sensitivity of the TA-700 squib. This decrease is approximately the same for both lots of squibs even though the normal sensitivity of each lot is slightly different. The standard dèviations are not greatly altered by the conditioning currents. After the completion of this test series no additional TA-700 squibs were available for conditioning tests using time intervals shorter than 1 hour. It is reasonable to assume, however, that shorter conditioning times would have some effect upon the firing sensitivity. In lot TA7-77-01

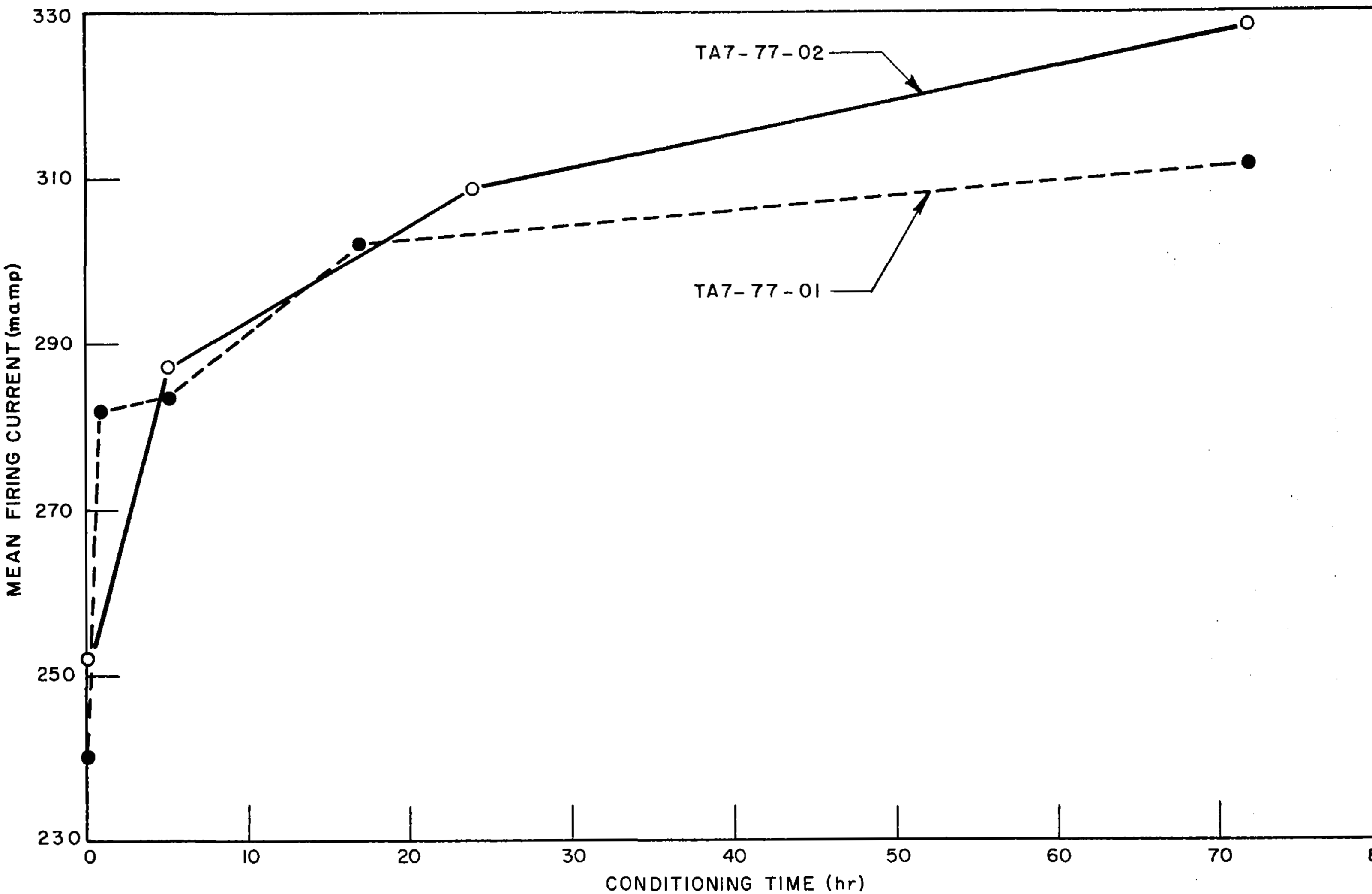

FIG. 6 MEAN FIRING CURRENT AS A FUNCTION OF NO-FIRE CONDITIONING TIME FOR THE TA-700 SQUIB

a conditioning time of 1 hour raised the mean firing current from 240 to 283 milliamperes. A lessor conditioning time would probably place the mean firing current between these levels.

Table 13

MEAN FIRING SENSITIVITIES OF TA-700 SQUIBS
CONDITIONED FOR VARIOUS TIMES AT THE M-5σ LEVEL

Conditioning Time (hours)	Lot TA7-77-02		Lot TA7-77-01	
	Mean Sensitivity (ma)	Std-Dev. (log units)	Mean Sensitivity (ma)	Std-Dev. (log units)
0	239.7	.0109	251.4	.0114
1	281.8	.01311	-----	-----
5	283.6	.0152	287.0	.0057
17	302.3	.0122	-----	-----
24	-----	-----	308.5	.0117
72	311.7	.0113	318.2	.0055

4.2.2 Functioning Time

During the test series in which the two lots of TA-700 squibs were subjected to the no-fire current level for varying lengths of time the functioning times of the squibs when fired in the Bruceton tests were recorded. The average values of these functioning times for each conditioning time are tabulated in Table 14 and plotted in Figure 7.

It is obvious that the functioning time is increased by the conditioning current even after a period of 1 hour. For comparison a small group of TA-700 squibs from lot TA7-77-02 was subjected to a series of successive increment prepulses in the manner discussed in Section 4.2.1 using a ΔI of 10 milliamperes. These squibs were then fired in a Bruceton test. The average functioning time of the items which fired was 2.234 seconds. This value is about twice as long as the longest time shown in

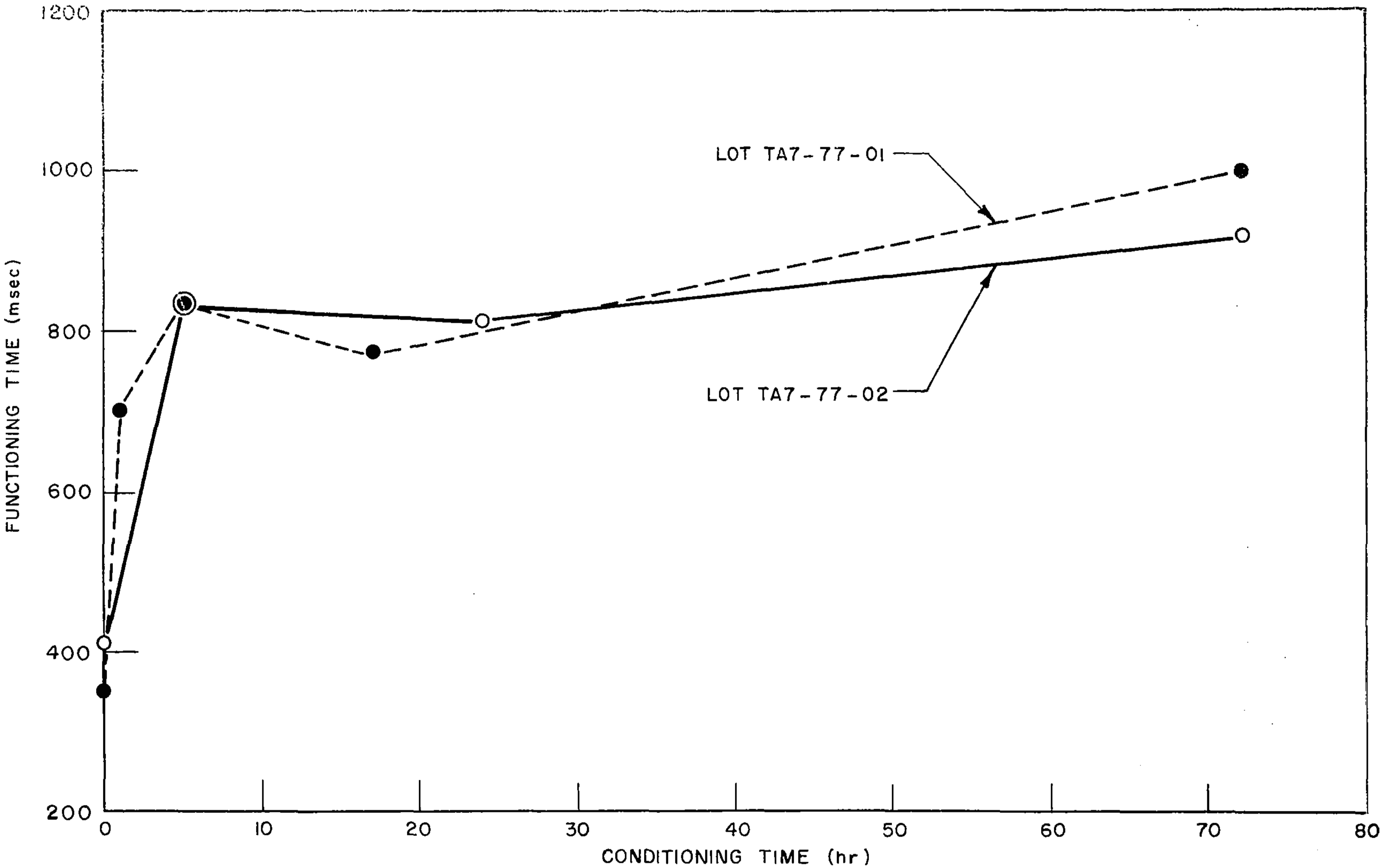

FIG. 7 FUNCTIONING TIME AS A FUNCTION OF NO-FIRE CONDITIONING TIME FOR THE TA-700 SQUIB

Table 14

AVERAGE FUNCTIONING TIMES OF TA-700
SQUIBS CONDITIONED WITH THE M-5σ CURRENT

Conditioning Time (hours)	Average Functioning Time (ms)	
	Lot TA7-77-01	Lot TA7-77-02
0	349.	414.
1	703.	----
5	835.	815.
17	777.	----
24	----	811.
72	1037	920.

Table 14 for the 72 hour conditioning period. Besides indicating further that the functioning time of this squib is radically altered by the application of prepulses, the severity of the successive increment test is well illustrated by these results.

Incidently, the mean firing current for the TA-700 squibs subjected to the successively incremented prepulses was 322 milliamperes - about the same mean as the squibs which were conditioned for 72 hours at the M-5σ level.

4.2.3 Dynamic Resistance

The dynamic resistance of unconditioned, new TA-700 squibs was measured at currents of 0.8, 1.47, 3.50 and 7.55 amperes. A quantity of TA-700 squibs was then pulsed with 10 second, constant current pulses according to the plan described in Section 4.2.1 A ΔI of 10 milliamperes was used.

Table 15

DYNAMIC RESISTANCE OF CONDITIONED AND UNCONDITIONED TA-700 SQUIBS

Input Current (amps)	Dynamic Resistance (ohms/sec)	
	Conditioned	Unconditioned
0.80	39.7	42.3
1.47	130	161
3.50	717	807
7.55	2670	2500

The dynamic resistance of the conditioned squibs was also measured at current levels of 0.8, 1.47, 3.50, and 7.55 amperes and compared with the unconditioned squibs. The dynamic resistances of both groups of TA-700 squibs are listed in Table 15 and plotted in Figure 8. There is no significant difference in the dynamic resistance of the two groups of squibs.

4.2.4 Thermal Time Constant

The thermal time constants for a quantity of new, unconditioned TA-700 squibs were determined using the technique described in Appendix B. Another quantity of the squibs was subjected to 10 second, constant current successive increment pulses starting at the mean-5σ level and increasing in 10 milliampere steps until the mean+5σ level was reached. The thermal time constants of the pulsed squibs were also determined.

Table 16 lists the thermal time constants of the pulsed and unpulsed squibs. The slight difference between the average thermal time constant of the pulsed group and the unpulsed group is of little statistical or, much less, practical significance.

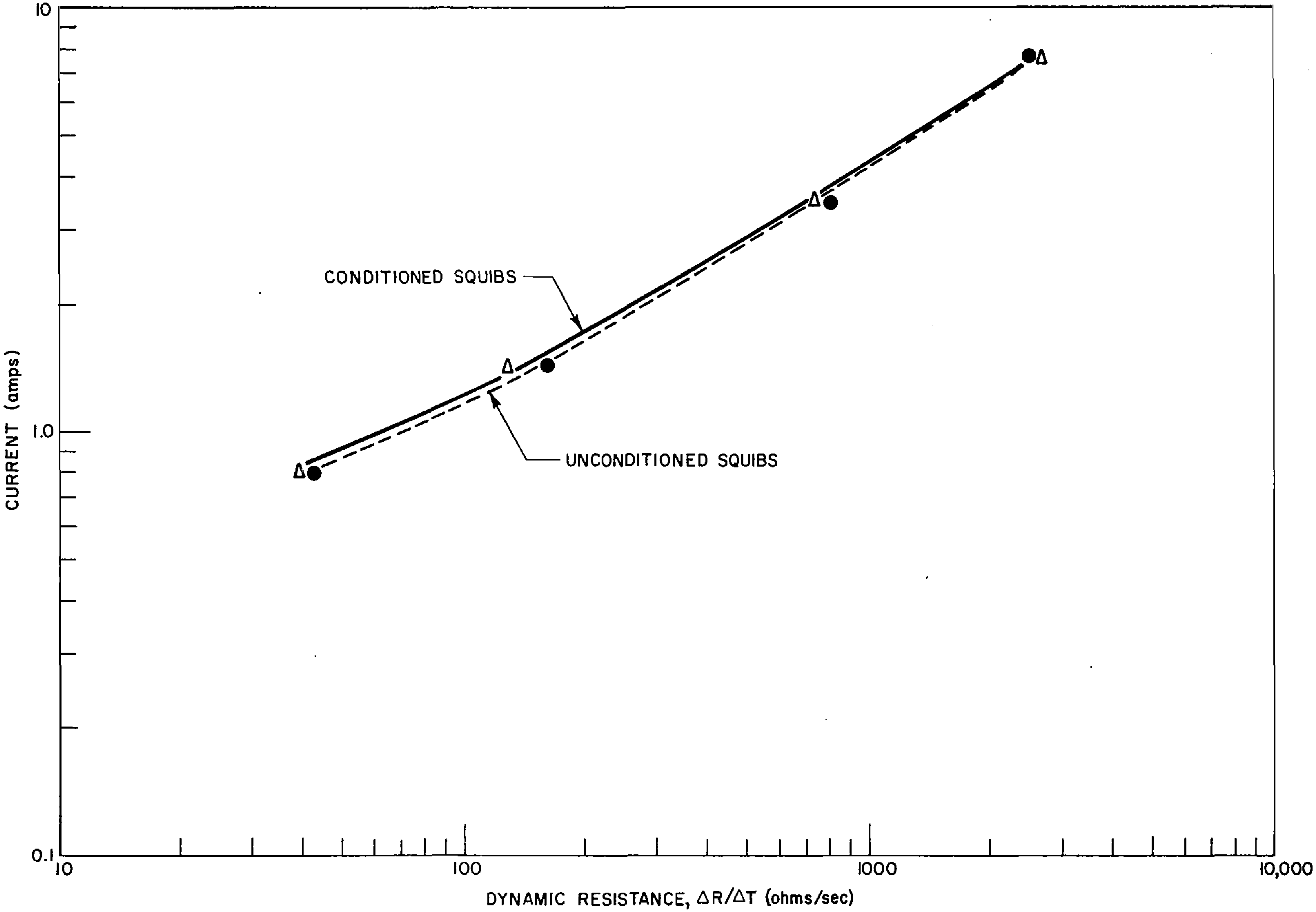

FIG.8 DYNAMIC RESISTANCE OF CONDITIONED AND UNCONDITIONED TA-700 SQUIBS

Table 16

THERMAL TIME CONSTANTS OF CONDITIONED AND UNCONDITIONED TA-700 SQUIBS

Thermal Time Constant (millisec.)	
Conditioned	Unconditioned
9.4	9.4
12.0	13.7
10.7	9.3
10.7	7.0
10.3	10.3
12.0	10.1
12.7	7.5
12.7	8.3
10.3	15.3
13.3	9.7
Avg. = 11.4	Avg.= 10.1

4.2.5 Bridgewire Power Sensitivity

Using the technique described in Appendix B the bridgewire power sensitivities of ten TA-700 squibs were measured. Maximum measuring current was limited to about 75 milliamperes. The initial resistance and bridgewire power sensitivities are listed in Table 17. Note the rather high power sensitivity value for squib #6. According to the relationship discussed in Section 4.1.5 this squib should be more sensitive than the others.

After measuring the ten squibs each was then prepulsed with 10 second, constant current pulses startint at 220 milliamperes and increasing in 10 milliampere steps until 300 mi-liamperes was reached. 300 milliamperes is well past the M+5σ level. After the final pulse was applied, the bridgewire resistance and power sensitivity were again measured.

Table 7

RESISTANCE AND BRIDGWIRE POWER SENSITIVITY OF TA-700 DELAY SQUIBS BEFORE AND AFTER CONDITIONING

	Unconditioned		Conditioned	
Item #	R_o (ohms)	$R_o\ \Delta R/\Delta P$ ($ohms^2$/watt)	R_o (ohms)	$R_o\ \Delta R/\Delta P$ ($ohms^2$/watt)
1	2.294	1.831	2.368	3.015
2	2.175	1.624	2.224	2.015
3	2.134	1.347	2.155	1.956
4	2.421	1.769	2.506	2.760
5	2.270	1.793	2.313	2.215
6	2.346	3.773	Squib Fired	
7	2.118	1.462	2.171	2.510
8	2.330	1.741	2.415	2.700
9	2.232	1.500	2.309	2.470
10	2.186	1.583	2.232	2.353
Avg	2.251	1.627*	2.299	2.443

*Squib #6 reading not included in this average.

The results of these measurements are also shown in Table 17. Note that squib #6 which showed a rather high bridgewire power sensitivity did indeed fire. In fact, it fired at the first prepulse level which is 220 milliamperes. The level is 2 milliamperes lower than the 0.1% firing probability level with 90% confidence. We would expect such an occurrence to be rare; however it serves to point out the caution which must be taken when using an EED of high sensitivity. The practical usefulness of a non-destructive sensitivity technique is apparant from this occurrence.

In addition to the firing of squib #6 there are two additional points of interest in this study. One is that the bridgewire resistance has increased by an average of 2% due to the prepulsing. The other is that the measured average bridgewire power sensitivity has increased by 50%. Since, we mentioned previously that

$$\text{Constant Current Firing Level} = k \left[\frac{1}{R_o \; (\Delta R/\Delta P)} \right] + k_2$$

and we have found the TA-700 squibs to be desensitized by prepulses, there seems to be conflicting evidence.

The failure of the power sensitivity technique to correlate with a known decrease in firing sensitivity due to prepulsing points out, in this case, that the correlation given in the above equation is not all inclusive. Apparently the factors which have caused the squib to be desensitized have not reflected themselves in the power sensitivity readings. The fact that the spot charge in the TA-700 is surrounded by air may affect the relationship.

The increase in resistance is not so easily explained. The seemingly small 2% change is significant since the error in our measuring equipment is about 1/4%. The squibs which underwent the change (all of which were prepulsed) were remeasured at several 24 hour intervals and found to be the same so that the change is a permanent one.

To further clarify the nature of the bridgewire power sensitivity and resistance increases due to prepulses 10 additional TA-700 squibs were prepulsed according to the scheme discussed in Section 4.2.1. After each pulse, however, the bridgewire resistance and power sensitivity were measured. These readings, averaged for the ten squibs at each prepulse level, are plotted in Figure 9.

The bridgewire resistance appears to increase sharply after the first current pulse of 220 milliamperes. Thereafter there was a gradual increase until 290 milliamperes where it again increased sharply. The sharp increase of resistance at the highest current pulse suggests that heating of the bridgewire and subsequent annealing may cause the resistance change.

The bridgewire power sensitivity remains fairly constant after the first or second prepulse but begins to increase at the 270 milliampers level. Perhaps the bridgewire temperature at this level is such that the LMNR or the potassium chlorate in the ignition spot undergo allotropic or chemical changes.

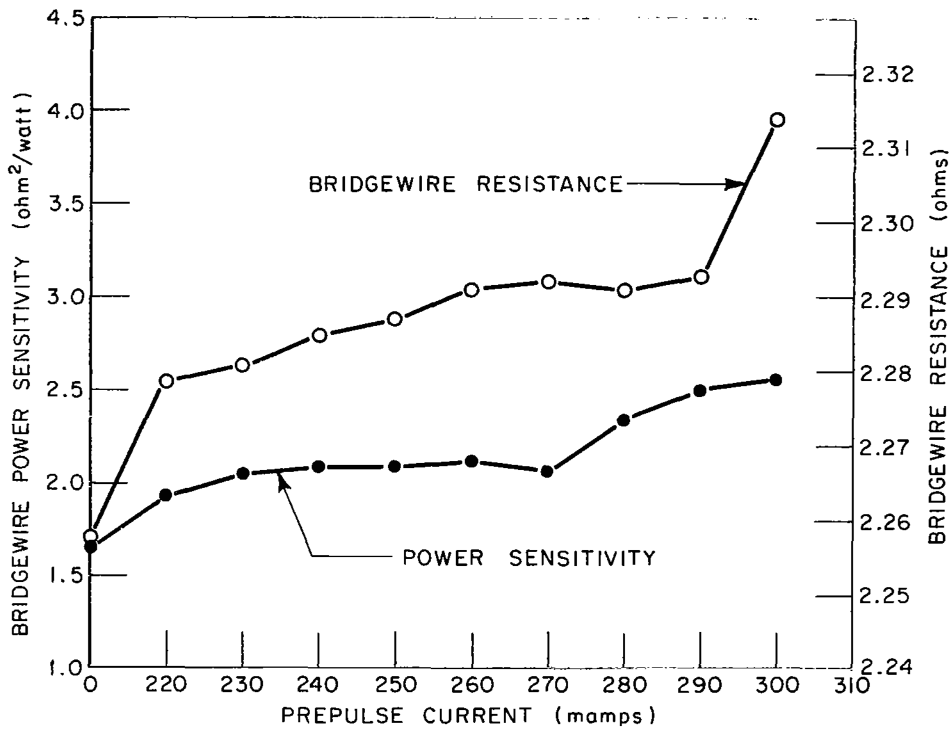

FIG. 9 BRIDGEWIRE POWER SENSITIVITY AND BRIDGEWIRE RESISTANCE AS A FUNCTION OF PREPULSE CURRENT (TA SERIES DELAY SQUIB)

5. SUMMARY AND CONCLUSIONS

During this project two major tasks have been accomplished: (1) Currently used pretesting practices have been surveyed with a questionnaire, (2) using the survey as a guide actual tests have been performed on various EEDs to determine if the EEDs were susceptible in any way to pretests. Specific tests were performed on the FOX, COMMAND, DART, and TA-700 squibs and the MASSEY-1000 igniter. The combination of the questionnaire answers and the results of the experimental studies have yielded results which are of both a particular and a general nature.

The pretest questionnaire has given a good insight to the currently used pretest practices employed by both users and manufacturers. Resistance and continuity checks, no-fire or "one-amp, one-watt" tests, voltage breakdown or dielectric strength tests and electrostatic tests are performed by practically all users and manufacturers who replied to the questionnaire. The most severe pin-to-pin test in our opinion, is the no-fire test, since it may result in harmful bridgewire temperatures. Much experimentation was therefore conducted on the effects of the no-fire test on EED firing parameters. In the realm of bridge-to-case and bridge-to-bridge type tests we have seen little or no evidence that either the electrostatic or the dielectric strength tests causes changes in the firing characteristics of typical EEDs.

More specifically, the highlights of the experimental studies are as follows:

500 Volt "Megger" Test

An exaggerated version of the 500 volt "Megger" test which is actually a voltage breakdown test was applied to COMMAND squibs, FOX squibs and 1000 igniters. The conditioned EEDs were then tested to see if changes had occurred in certain selected performance parameters. No significant alterations in the normal performance parameters were detected as a result of the voltage breakdown pretest. Even the electrostatic sensitivity, that is, the vulnerability of the EED to a pulse of high voltage applied from bridge-to-case, was not significantly altered by this pretest. It was thought that this parameter would undergo a change since the 500 volt breakdown test is applied from bridge to case and could conceivably enhance any breakdown paths present in the EED under test. The lack of positive results with this test series does not necessarily prove that the voltage breakdown or dielectric strength tests will not affect the performance of other EEDs. Where unusual configurations or conductive mixes are used the performance of the EED may be affected. It is possible that the reliability of an EED may be significantly reduced in some cases since the bridge-to-case type tests may sensitize the EED to this mode of firing. Further investigation with EEDs of other configurations and ignition mixes is indicated.

Pin-to-Pin Pretests

The DART and the TA-700 squibs were used to study the effects of the pin-to-pin type pretests. In each case the constant current sensitivity to pulses of 10 second duration, the functioning time, the dynamic resistance, the thermal time constant, and the bridgewire power sensitivity were studied to see if changes could be caused by the application of normal pretests and pretests of exaggerated severity.

The constant current sensitivity, functioning time, possibly thermal time constant and bridgewire power sensitivity of the DART squib were significantly altered only by the severe conditioning afforded by the successive increment technique. Conditioning with the no-fire current, the most severe pin-to-pin pretest normally applied by users and manufacturers of EEDs, even for 72 hours did not alter these parameters. These results, combined with the completely negative results obtained with the dynamic resistance tests, would seem to indicate that the DART squib is not affected by the normal pin-to-pin pretests. The increase in the functioning time of the DART squib due to the application of successively increasing current pulses is interesting. Since no-fire pulses applied for only an hour to the TA-700 squib caused a similar increase in functioning time the effect may be common to many EEDs and should be studied in more detail.

The dynamic resistance and the thermal time constant of the TA-700 squib were not significantly affected by any type of conditioning pulse. The sensitivity to constant current, 10 second pulses and the functioning time were affected by application of the no-fire current for extended periods of time. In these tests groups of TA-700 squibs were subjected to the no-fire current level for periods ranging from 1 to 72 hours. The conditioned squibs were then fired in Bruceton tests to determine the constant current sensitivity and functioning time. Conditioning times of only one hour caused a decrease of 15% in sensitivity and an increase of 100% in functioning time. Longer conditioning times caused slightly greater changes in these parameters. These effects occurred with two different lots of TA-700 squibs. Changes were also detected in the bridgewire power sensitivity and bridgewire resistance due to conditioning with successive increment pulses.

The scope of this program was such that detailed investigations of all the observed effects could not be carried out. The studies which were conducted, while yielding information of a particular nature about the EEDs which where used in the experiments, can be applied on a more general level if we concede that the EEDs used were representative types. Desensitization of the TA-700 squib, for instance, brought about with currents of the same magnitude as those used in present-day pretests, or the lengthening of the functioning time certainly raise questions as to applying no-fire pretests to all EEDs. The negative effects with the voltage breakdown pretest suggest that this test may not be harmful for the majority of EEDs.

A theoretical approach for the assessment of the vulnerability of EEDs to pin-to-pin type pretests has been presented. In order to apply this technique some knowledge of the EED bridge configuration and the properties of the surrounding explosive material is necessary. As we have pointed out, the gathering of this knowledge, though difficult, may sometimes prove easier than performing tests of the type used in this study. If further investigation of the effects of pretests on specific EEDs is to be carried out, a combination of a theoretical and a practical approach should be employed.

This study has shown that pretest effects do exist which require additional study. Each individual EED has reacted in a different manner to pretests. This shows caution must be exercised in making generalizations until the significant squib variables and the actual mechanisms of degradation are identified. In addition to the inherent variations in performance for a particular squib design there will be fluctuations introduced by lot to lot variations and to some extent, measurement errors. It is recommended, therefore, that additional study of pretesting effects be performed on both a general and a particular basis. The work carried out during this investigation has only paved the way for future studies.

APPENDICES

A. Pretest Questionnaire

B. Description of Tests Used in Pretest Studies

C. Constant Current Control Tests On DART and TA-700 Squibs

APPENDIX A

Pretest Questionnaire

SURVEY OF EED ELECTRICAL PRETESTING PRACTICES

1.0 Specific Measurements Made

1.1 Bridge Resistance

a. Current level? ____________________

b. Instrument? ____________________

c. Number of applications per unit? ____________________

d. Percentage of lot tested? ____________________

1.2 Voltage Breakdown or Dielectric Strength

a. Voltage levels? ____________________

b. Current limitation? ____________________

c. Instrument? ____________________

d. Number of applications per unit? ____________________

e. Percentage of lot tested? ____________________

f. Criteria for acceptance? ____________________

1.3 Static Electricity

a. Voltage levels? ____________________

b. Capacitance values? ____________________

c. Modes? (pin-to-case, bridge-to-bridge, etc.) ____________________

d. Number of applications per unit? ____________________

e. Percentage of lot tested? ____________________

f. Criteria for acceptance? ____________________

1.4 No-Fire Currents

a. Time of application? ____________________

b. Number of applications per unit? ____________________

c. Percentage of lot tested? ____________________

1.5 No-Fire Currents (one amp - one watt types)

a. Time of application?____________________

b. Number of applications per unit?____________________

c. Percentage of lot tested?____________________

1.6 RF Susceptibility

a. Method of testing?____________________

b. Frequencies?____________________

c. Power levels?____________________

d. Time of application?____________________

e. Number of applications per unit?____________________

f. Modes?____________________

g. Percentage of lot tested?____________________

1.7 Other Tests

a. Method of testing?____________________

b. Time of application?____________________

c. Number of applications per unit?____________________

d. Modes?____________________

e. Percentage of lot tested?____________________

2.0 Available Hardware

2.1 Can you furnish any EED's that might be of interest to NASA for evaluation if NASA pays for the evaluation?____________________

____

2.2 Would you like to fund any evaluations?____________________

____

3.0 Recommendations or Problem Areas of Interest

3.1 Have you conducted any evaluations of this nature, or have any test data on this subject? Reports?____________________

____

3.2 Do you have any recommendations or questions that you would like to include in this evaluation?________________________________

____

____

____

____

____

4.0 Publication

4.1 May we publish the information you supply?________________________

4.2 Would you prefer that your reply remain anonymous?______________

4.3 Would you like to receive the results of this study?____________

Please address replies
to
The Franklin Institute Research Laboratories
Applied Physics Laboratory
20th and Parkway
Philadelphia, Penna. 19103
Attn: R. G. Amicone

APPENDIX B

Description of Tests Used in Pretest Studies

CONSTANT CURRENT SENSITIVITY AND FUNCTIONING TIME

The equipment used for the constant current evaluations is The Franklin Institute Laboratory Universal Pulser (FILUP). This instrument is capable of controlling the current and the time of application to within 1%. The constant current sensitivity of EED's in this program was determined by the Bruceton method with constant current applied to the bridgewire for a maximum of 10 seconds and the functioning time, if any, recorded. Functioning time, as we define it, is the interval between the application of a firing pulse to an EED and the output of a photo-sensitive detector that responds to the flash resulting from the initiating EED. The results of sensitivity tests are analyzed to yield the currents necessary to produce firing probabilities of 99.9%, 50.0%, and 0.1% with 95% confidence.

DYNAMIC RESISTANCE

Upon application of an input stimulus to the bridgewire system of an EED the wire element undergoes dynamic resistance changes, which are related to the thermal properties not only of the wire but of its environment. The dynamic resistance characteristics often reflect functioning abnormalities that might otherwise go undetected, such as a discontinuity in the functioning time response; or bridgewire rupture (for high input currents) before adequate energy has been transferred to the surrounding explosive to cause initiation.

Dynamic resistance, or the time rate of change of bridgewire resistance of EED's is determined by passing a known constant current through the bridgewire (usually, with The Franklin Institute Laboratories Universal Pulser, FILUP) and recording the voltage drop across the bridgewire as a function of time. An oscilloscope is generally used to record the voltage drop as a function of time. Due to the magnitude of the currents used to make the dynamic resistance measurements the bridgewire is almost always broken, i.e., the EED is destroyed. The manner in which a dynamic resistance oscillograph trace is interpreted is illustrated in Figure A1. Since we know the current which was applied to the bridgewire we can simply divide the current into the change in voltage (ΔV) to yield the change in resistance (ΔR). A division of Δt into ΔR then gives us the value of dynamic resistance in ohms/second.

THERMAL TIME CONSTANTS

Thermal time constant is defined as the time required for the bridgewire temperature to decay to 36.8% of the maximum temperature excursion after application of an input stimulus. Thermal time constant is determined in the following manner: a small current is passed continuously through the bridgewire of the EED before, during, and after the application of a large current pulse of short duration. The monitoring current, which is held constant by the inclusion of a relatively large series (current limiting) resistor, is small enough not to cause any appreciable changes in the bridgewire resistance. Since the monitoring current is constant, it is possible to use the potential across the bridgewire observed with an oscilloscope as a continuous measure of the instantaneous value of resistance as the wire cools.

CONSTANT CURRENT SUCCESSIVE INCREMENTED PULSES

To determine the qualitative effect of constant current prepulses on the sensitivity of EED's we use a successive increment test, which is a series of constant current pulses of equal duration, starting at a relatively low level, usually about five standard deviations ($m-5\sigma$) below the current necessary to produce a firing probability of 50%. With each successive pulse the current is increased by a fixed amount until the EED fires or some pre-determined high current is reached. The interval between pulses must be long enough for the bridgewire to return to ambient temperature to avoid thermal stacking. If the sensitivity of the device under test is not affected by prepulsing, then we would expect it to fire at a current pulse near or about the mean current established by a control test. When several EED's are fired in this manner, the overall average firing current and standard deviation may be computed.

If prepulsing has any effect, we can expect one of two results. Either the device may become more sensitive, which is improbable; or its sensitivity may be degraded. If the sensitivity of an EED is decreased by prepulsing, the decrease probably occurs in the following manner.

The initial or first prepulse ($m-5\sigma$) will desensitize the EED by some small amount so that the probability of firing by the second prepulse is reduced. The second pulse causes further desensitizing, so that the third pulse is less likely to cause firing. This step-by-step desensitizing continues; hence, if the increment between prepulses is kept small enough, the sensitivity of the device may be pushed beyond the arbitrary upper limit of ($m+5\sigma$) long before the pulse amplitude becomes large enough to fire the item. On the other hand, if the current increment between prepulses is large enough to overshadow, to some extent, the change in sensitivity, firing will occur somewhere between the normal sensitivity point and the upper limit.

NONDESTRUCTIVE MEASUREMENTS

For the past several years, under the sponsorship of Picatinny Arsenal, our laboratory has been investigating the relationship between nondestructive measurements and the firing sensitivity of electroexplosive devices (EED's)[1]. This research has reached the point where it can be applied to many EEDs with the expectation that some degree of correlation will be found between the constant current firing sensitivity and the electrothermal parameters that can be measured without degrading the EED.

The parameters that are measured are R_o (initial resistance) and $\frac{\Delta R}{\Delta P}$ (power sensitivity), where the latter is defined as the change in bridgewire resistance for a corresponding increase in input power. We

---

[1] Army Contract No. DA-36-034-501-ORD-3115RD Reported in FIRL Reports MU-A2357-10 through 43.

have found that a predictable inverse relationship exists between the product $R_o \frac{\Delta R}{\Delta P}$ and the current required to fire EEDs. The current necessary to fire a wire bridge EED can often be estimated, on a relative basis, by measuring only R_o; but a higher degree of correlation can be had by using the product $R_o \frac{\Delta R}{\Delta P}$. One great advantage of using $R_o \frac{\Delta R}{\Delta P}$ instead of R_o is that the former can detect abnormal thermal environments around the bridgewire such as the absence of the spot charge.

To classify a test as nondestructive, one must be able to make all measurements without altering or degrading the normal firing sensitivity of the test item. Past experience with several EEDs indicates that there are usually no changes in the normal firing sensitivity caused by measuring R_o or $\frac{\Delta R}{\Delta P}$ by the following procedure. Both R_o and $\frac{\Delta R}{\Delta P}$ are measured with a resistance bridge circuit shown in Figure A1, where X represents the device being tested, and the series resistors at A or B limit the current through the detonator to 1 milliampere. When the bridge is balanced, R_o is recorded. The bridge is then unbalanced by increasing R_1 by a known amount (this is ΔR) and the current is increased to bring the bridge back into balance. The voltage drop across the detonator, due to this increased current, is measured and the power is computed, $P = \frac{E^2}{(R_o+\Delta R)}$. The change in power ($\Delta P$) necessary to balance the circuit is actually the power necessary to balance the bridge for a known R minus the power necessary to measure R_o. The power needed to measure R_o is so small it is always neglected in these calculations.

The relationship which we have found[2] between R_o and the constant current sensitivity is given approximately by

$$\text{Cons. Cur. Sens.} = k_1\left(\frac{1}{\Delta R/\Delta P}\right) + k_2,$$

where k_1 and k_2 are constants.

[2] loc. cit.

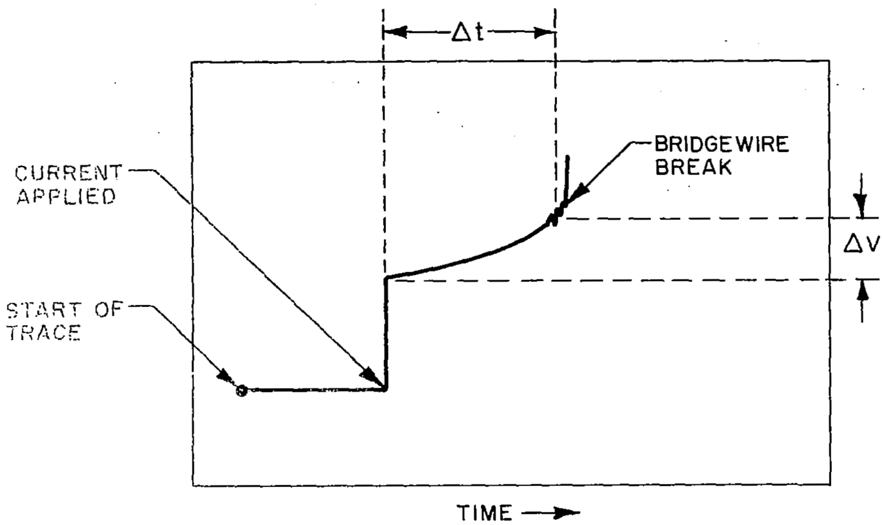

FIG. B-1. INTERPRETATION OF DYNAMIC RESISTANCE OSCILLOGRAPH

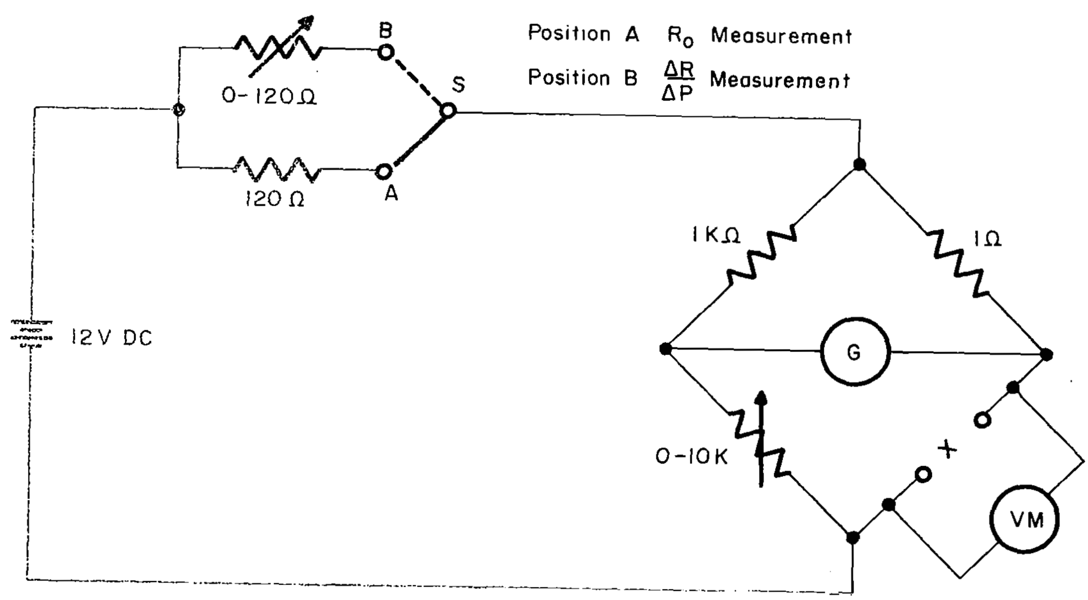

FIG. B-2. CIRCUIT FOR R_0 AND $\frac{\Delta R}{\Delta P}$ MEASUREMENTS

APPENDIX C

CONSTANT CURRENT CONTROL TESTS on DART and TA-700 Squibs

TEST NO.

TYPE OF TEST: Constant Current

Frequency

Pulse Width 10 sec

Rep. Rate

ITEM: DART

LOT NO. --

TEMP.: Room Conditions

HUMIDITY

Functioning Levels (ζ)

ITEM NO.	1.20	1.26	1.32	1.38	1.44	FUNCT. TIME (milli secs)	RESISTANCE (Ω)
1			0				.23
2				X		69.39	.23
3			X			51.39	.23
4		X				55.15	.20
5	0						.25
6		0					.23
7			X			8.90	.22
8		0					.23
9			X			4.66	.25
10		X				40.60	.23
11	0						.25
12		0					.23
13			X			7.32	.24
14		0					.25
15			0				.23
16				X		11.02	.24
17			X			8.03	.23
18		0					.22
19			0				.25
20				X		52.27	.23
21			X			6.36	.22
22		0					.20
23			X			24.03	.23
24		X				18.26	.22
25	0						.25
26		X				79.90	.25
27	0						.23
28		0					.22
29			0				.23
30				0			.25
31					X	9.67	.24
32				0			.25
33					X	6.68	.22
34				0			.23
35					X	32.87	.22
36				X		22.45	.23
37			0				.22
38				X		18.14	.23
39			0				.24
40				X			.22
41							
42							
43							
44							
45							
46							
47							
48							
49							
50							
X						N_x = 20	
O						N_o = 20	

i	i^2	N_o	N_x	ζ = A
0	0	4	0	1.20
1	1	7	4	
2	4	6	7	
3	9	3	6	
4	16	0	3	
5	25			
6	36			
Totals:		N_o = 20	N_x = 20	

Special Parameters

$c = (\log \zeta)_{i=0}$ = 3.07918

$d = (\log \zeta)_{i+1} - (\log \zeta)_i$ = .02

Primary Statistics

$A = \Sigma\, i N$

$B = \Sigma\, i^2 N$

$M = (NB - A^2)/N^2$

$m = c + d\,(A/N \pm ½)$*

$\sigma = 1.62\, d\,(M + 0.029)\sqrt{\frac{N}{N-1}}$**

*Use + for "o's;" - for "x's"

**Valid for M ≥ 0.3 only, otherwise consult 'Bruceton Report' (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Ma-1

	For "o's"	For "x's"
A =	28	48
B =	58	134
M =	.94	.94
m =	3.11718	3.11718
σ =	.03220	.03220

Secondary Statistics

$m = \frac{N_o m_o + N_x m_x}{N_o + N_x}$ = 3.11718

$\sigma = \sqrt{\frac{N_o \sigma_o^2 + N_x \sigma_x^2}{N_o + N_x}}$ = .03220

$\bar{\zeta}$ = Antilog m = 1.310 Amps

DATE: Dec 5, 1966 | INITIALS: TT | PAGE

Probability Levels

P% = 99.9%

100-P% = .1%

Confidence Level

X% = 95%

m = 3.11718	k_p ② = 3.09
σ = .03220	k_x ② = 1.645
d = .02	G ③ = .955
$S = \frac{\sigma}{d}$ = 1.61	G^2 = .91202
N = 40	H ③ = 1.6
n ① = 20	H^2 = 2.56

① $n = \frac{N}{2}$ when N is even integer

$n = \frac{N+1}{2}$ when N is odd integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{G^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$$

= .06321

Final Calculations

(99.9%) (95% Conf) = $m + k_p\sigma + Y$

= 3.27988 log units

= 1.905 amps

(.1%) (95% Conf) = $m - k_p\sigma - Y$

= 2.95448 log units

= 0.905 amps

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C-3

TEST NO. 1	TYPE OF TEST: Constant Current	Frequency Pulse Width 10 sec Rep. Rate	ITEM: Squib (TA Series) Switch	SERIAL NO. TA-77-02	TEMP: Room Conditions	HUMIDITY

Functioning Levels (ζ)

ITEM NO.	245.5 ma	248.3 ma	257.1 ma	266.1 ma	FUNCT. TIME secs	RESISTANCE Ω
1		0				2.20
2			X		.396	2.20
3		0				2.20
4			X		.392	2.10
5		X			.412	2.20
6	0					2.36
7		X			.346	2.20
8	0					2.10
9		X			.502	2.20
10	0					2.10
11		0				2.20
12			X		.343	2.30
13		0				2.30
14			X		.367	2.30
15		0				2.20
16			X		.470	2.20
17		0				2.10
18			X		.358	2.20
19		0				1.00
20			X		.388	2.30
21		0				2.10
22			0			2.20
23				X	.390	2.20
24			X		.407	2.11
25		X			.391	2.20
26	0					2.30
27		X			.399	2.20
28	0					2.20
29		X			.395	2.20
30	0					2.10
31		0				2.20
32			X		.378	2.30
33		0				2.10
34			0			2.20
35				X	.359	2.30
36			0			2.10
37				X	.330	2.26
38			X		.428	2.10
39		0				2.20
40			X		.412	2.30
41						
42						
43						
44						
45						
46						
47						
48						
49						
50						

Average R = 2.12

Average FT = .391

N_x = 20 X

N_o = 20 O

i	i^2	N_o	N_x	ζ =
0	0	6	0	245.5
1	1	11	6	
2	4	3	11	
3	9	0	3	
4	16			
5	25			
6	36			
Totals:		N_o = 20	N_x = 20	

Special Parameters

$c = (\log \zeta)_{i=0} =$ 2.38005

$d = (\log \zeta)_{i+1} - (\log \zeta)_i =$ .015

Primary Statistics

$A = \Sigma\, i N$

$B = \Sigma\, i^2 N$

$M = (NB - A^2)/N^2$

$m = c + d\,(A/N \pm \tfrac{1}{2})^{*}$

$\sigma = 1.62\, d\,(M + 0.029)\sqrt{\frac{N}{N-1}}$ **

*Use + for "o's;" - for "x's"

**Valid for M ≥ 0.3 only, otherwise consult 'Bruceton Report' (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Ma-1

	For "o's"	For "x's"
A =	17	37
B =	23	77
M =	.42750	.42750
m =	2.4003	2.4003
σ =	.01137	.01137

Secondary Statistics

$m = \frac{N_o m_o + N_x m_x}{N_o + N_x}$ = 2.4003

$\sigma = \sqrt{\frac{N_o \sigma_o^2 + N_x \sigma_x^2}{N_o + N_x}}$ = 0.01137

ζ = Antilog ... ma

DATE

Probability Levels

P% = 99.9%

100-P% = .1%

Confidence Level

X% = 95%

m =	2.4003	k_p ② =	3.09
σ =	.01137	k_x ② =	1.645
d =	.015	G ③ =	1.047
$S = \frac{\sigma}{d}$ =	.758	G^2 =	1.09620
N =	40	H ③ =	1.29
n ① =	20	H^2 =	1.66410

① $n = \frac{N}{2}$ when N is <u>even</u> integer

$n = \frac{N+1}{2}$ when N is <u>odd</u> integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{G^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$$

= .01827

Final Calculations

(99.9%) (95% Conf) = $m + k_p\sigma + Y$

= 2.45370 log units

= 284.3 ma

(.1%) (95% Conf) = $m - k_p\sigma - Y$

= 2.34690 log units

= 222.3 ma